HABITAT AND PLANT DISTRIBUTIONS IN HANGING GARDENS OF THE NARROWS, ZION NATIONAL PARK, UTAH

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Abstract.— Hanging gardens are insular plant communities of the Colorado Plateau. This study examines hanging gardens in the Narrows, Zion National Park, Utah. The floristic similarity of gardens and the presence of species in classes of variables which characterize the habitat are disclosed. Although the gardens are isolated and dissimilar, the individual species are not restricted in the range of habitat found. Floristic dissimilarity cannot be attributed to differences in habitat. These results are compared to studies of hanging gardens in eastern Utah.

Hanging gardens are plant communities growing at seeps on the canyon walls of the Colorado Plateau. The hanging garden environment is characterized by shallow soils at a seep from bedrock. Seeps occur where water has percolated through a porous formation until meeting a less permeable layer of rock. Then the water flows laterally until a canyon intersects this plane. The narrow canyons often shade the hanging gardens. Compared to other environments of the Colorado Plateau, the hanging gardens are cool and moist.

The Narrows of the North Fork of the Virgin River in Zion National Park is an archetypal hanging garden locale. In an 8 km section there are about 60 gardens, varying in size from a few square centimeters to over 100 m^2. Most of these are at permanent seeps with small discharges of water. The hanging gardens of the Narrows assume a variety of shapes, but in general they occupy a place where erosion has modified the steepness of the canyon wall. Often these places are horizontal bands. Other gardens occur where vertical jointing has concentrated the seepage. Some gardens occupy remnants of potholes, and others are on bulges of travertine. A few are in alcoves. Most hanging gardens in the Narrows are close to the level of the river, where they may be vulnerable to flash floods.

This study examines the relationship between the plant species and the habitat in the hanging gardens of the Narrows. The concepts of Ramensky (1924) and Gleason (1926) are the basis for hypothesizing that the presence and importance of species at sites are determined by their individual tolerances and requirements in relation to the habitat. This idea can be evaluated by examining the floristic similarity between sites and the incidence of species across a range of variables that characterize the biotopes. The hypothesis leads one to expect a positive relationship between floristic similarity and similarity of biotope (i.e., if sites represent a single habitat).

A few authors have investigated the vegetation of hanging gardens. In a general ecological study of Zion National Park, Woodbury (1933) outlined the stages of primary succession that occur at seeps. Welsh and Toft (1976) described a variety of garden types in Glen Canyon, Utah, based on the form created by the erosion of the rock, and traced the geographical affinities of the species they found. They called hanging gardens "relictual refugia" because the gardens provided sites for species from other southwest locations, boreal forests, and earlier epochs. Welsh and Wood (1976) concluded that hanging gardens have a stable structure, attributing change in species importance measured over a one-year interval to measurement error. Wood and Welsh (1976) found productivity to be relatively high for this

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type of vegetation, and presumed it to be steady.

Nebeker et al. (1977) believed that the floristic dissimilarity found in hanging gardens of eastern Utah indicated "random assortments of individuals capable of exploiting the environments of individual sites." They conclude that over 25 percent of the species were ecological specialists of hanging garden habitats, within the Colorado Plateau region. A few studies briefly mention hanging gardens. Clover and Jotter (1944), Flowers (1959), and Loope (1976) describe hanging gardens in general ecological studies of the Colorado River area. Raines (1976) noted that hanging gardens can be critical habitats for small mammals in drought years. All these studies emphasize the importance of habitat and support the hypothesis of this study.

METHODS

I sampled 29 hanging gardens in an 8 km section of the Narrows and in 0.75 km of a tributary (Orderville Canyon) between June and September 1977. Sites were chosen informally on the basis of access, but a representative range of garden sizes was sought. To estimate percent foliar cover of species, I recorded the number of decimeters intercepted by a species along line transects spaced at 2 m intervals and perpendicular to the long axis of each garden. In gardens numbered 1, 2, and 3, I placed a 2500 cm^2 quadrat every 2 m on transects spaced at 2 m intervals and recorded the number of 100 cm^2 grids occupied by each species. This method proved to be impractical, although in comparison tests the results were not significantly different.

From the values of relative cover for each garden, I calculated the similarity of each pair of hanging gardens according to Ruzicka's (1958) index:

$$SI = (\Sigma A/\Sigma B)(100)$$

where A is the smaller and B the larger value of a species in two sites, considering all species present in either site.

I measured 11 variables to characterize the biotope of each hanging garden. Soil and water pH at each site was measured colorimetrically (Microessential Laboratory 0.2 unit paper). I gathered grab samples of soil from the surface where there was any depth, not taking any litter. I took 125 ml samples of water from the seeps. In a few cases samples could not be taken because of a paucity of soil or water. The USDA Soils Testing Laboratory at Logan, Utah, measured soil and water conductivity as a surrogate of salinity, and the total phosphorous content of the soil. I measured the slope of each garden by taking the height:depth ratio and calculating a percent slope. I sampled soil depth every 4 m across the center of each garden with a wire rod to obtain a single average soil depth measure; in smaller gardens, one or two evenly spaced measures were taken.

Direct solar radiation was derived by a computer program of Williams et al. (1972), which accounts for slope, azimuth, and latitude of the site, and intervening topography that shades the site. The program computes the calories per square centimeter for any one day, and I summed the 120th, 180th, and 240th days of the year to bracket the growing season. The scale of resolution does not account for all possible variations in microrelief. In locations with particular sunblocking features, such as alcoves, I reduced the computed value 10 percent. At one garden where the three-day sum was zero, although I observed direct radiation at the site, I arbitrarily assigned a value of 50 cal/cm^2.

I measured three spatial variables: area, isolation, and distance to the Gateway to the Narrows Trail. I derived the area of each garden from the grid formed by the species intercept transects. Isolation is defined here as the sum of the distances from each garden to its nearest three neighbors. These distances were measured on a topographic map (ZNHA 1977). The Gateway to the Narrows Trail is the scene of much pedestrian tourist traffic, but above the terminus human use declines rapidly. The distance to the trail, also measured on the topographic map (ZNHA 1977), may affect invasion by nonnative species.

I analyzed the relationships between species presence and absence and the 11 environmental variables. These variables were considered separately because there was low correlation between any two. I followed

Strahler's (1978) use of the G_H statistic to disclose significant differences between species presence and absence in ordinal categories of the environmental variables. Although the data are ratio scaled and the categories are ordinal, the presence of many zeros in the species matrix and the number of tie scores among the environmental variables make more powerful tests less dependable. Only the 13 most common species occur frequently enough to be tested. I divided each of the 11 environmental variables into four or five ordinal categories (Table 1). The number of categories and the ranges are arbitrary, except that each category represents at least one garden. I attempted to categorize the variables so that the results of the G_H tests would represent the relationships between species presence and a continuous change in the variable.

I also calculated a species-area curve of the gardens by a regression of log number of species on log area. Following the Whitehead and Jones (1969) treatment of island floras, I deleted the smallest garden on successive calculations to find the point below which the area detracted from the fit of the curve.

Results

Forty-eight species were counted in the 29 hanging gardens. Nine taxa were identified only to genus or family, and four rare plants could not be identified (Table 2). Richness ranged from 2 to 20. The frequency of occurrence ranged from 1 to 17. Although no species occurred in all gardens, the 13 species occupying five or more gardens are used here as diagnostic species, because species of moderate constancy are good indicators of variation in the environment (Mueller-Dombois and Ellenberg 1974). The many rare species (35 occupying less than five gardens) are simply not common enough to give useable correlations with garden environments. For complete tables of data on species cover, floristic similarity, and the environmental variables, see Malanson (1978).

The floristic similarity of the hanging gardens is low, ranging from 0 to 77, and averaging 10.23 for all gardens. This value of similarity is close to the results of Nebeker et al. (1977).

All hanging gardens provide a mesic to hygric biotope. For water and soil, values of pH ranged from 5.9 to 7.2 and 6.3 to 7.4, and values of salinity from 0.3 to 2.5 μmhos/cm and 230 to 1420 mhos/cm, respectively. In this study, average soil phosphorous content ranges from 2.1 to 84 ppm. Direct solar radiation varies from 0 to 683 cal/cm^2 for the three-day sum. Average soil depth ranges from 0.1 to 48.4 cm, but exceeds 10 cm in only three gardens. Slopes average between 40 percent and vertical. Area ranges from 2 to 100 m^2 among samples. Most values of isolation are low, 24 gardens are less than 300 m from the nearest three neighbors. All but four distances from the Gateway to the Narrows

TABLE 1. Classes of the environmental variables.

Variables	Classes 1	2	3	4	5
Area (m^2)	0–10	10–25	25–50	50	
Distance from trail (m)	500–1630	1631–2760	2761–3890	3891–5020	5021–6150
Isolation (m)	0–80	81–160	161–240	241–320	320
Phosphorous (ppm)	0–5.0	5.1–15	16–36	37–87	
Slope (percent)	1–50	51–125	126–275	276–525	526
Soil depth (cm)	0–1	1–2	2–4	4–8	8
Soil pH	6.3–6.4	6.5–6.6	6.7–6.8	6.9–7.4	
Soil salinity (mhos/cm)	0.1–0.4	0.5–0.8	0.9–1.2	1.3–1.8	1.9–2.5
Solar radiation (cal/cm^2)	0–150	151–300	301–450	451–600	601–750
Water pH	5.9–6.2	6.3–6.5	6.6–6.8	6.9–7.2	
Water salinity (mhos/cm)	0–300	301–600	601–900	900	

Trail are clustered bimodally between 500 and 2000 m and between 3000 and 5000 m.

The results of the species presence tests indicate that there are few relationships between gradients of the environmental variables and the presence and absence of important species in the sampled gardens (Table 3). Of the 143 tests, only 15 show a significant difference at p = 0.05, and one would expect 7 of the tests to prove significant by chance alone. Only solar radiation consistently returns significant results.

The hanging gardens are smaller isolates than those described by Whitehead and Jones (1969) (1.25 to 8.65 ha); yet the changing species-area curves are similar. The exclusion of the four smallest gardens (6 m^2) improves the regression coefficient from 0.55 to 0.67, and changes the slope from 0.28 to 0.48.

TABLE 2. Hanging garden plant species.

Species	Frequency
Abies concolor	1
Acer negundo	3
Adiantum capillus-veneris	15
Adiantum pedatum	6
Amaranthus graecizans	1
Anaphalis margaritaceae	4
Apocynum cannabinum	1
Aquiligia spp.	13
Aralia racemosa	12
Artemisia ludoviciana	1
Aster eatonii	8
Berberis repens	3
Brickelia grandiflora	1
Bromus ciliatus	3
Calamagrostis scopulorum	5
Cirsium arizonicum	1
Cystopteris fragilis	17
Dodecatheon pulchellum	9
Dryopteris filix-mas	2
Eleocharis sp.	3
Epipactis gigantea	3
Equisetum hyemale	1
Fraxinus velutina	3
Galium aparine	4
Hepaticae	10
Heuchera versicolor	2
Juncus sp.	2
Lobelia cardinalis	3
Mimulus cardinalis	13
Mimulus guttatus	1
Muhlenbergia andina	1
Muhlenbergia mexicana	2
Nasturtium officinale	2
Poa nevadensis	2
Rhus radicans	2
Rubus leucodermis	3
Rumex sp.	1
Salix sp.	1
Smilacina stellata	7
Sphagnum sp.	14
Sphagnaceae	9
Taraxacum officinalis	4
Thalictrum fendleri	2
Viola spp.	3
unidentified #1	1
unidentified #2	1
unidentified #3	2
unidentified #4	1

DISCUSSION

The biotopes of the hanging gardens were delimited in this study by the environmental variables of soil and water pH and salinity, soil phosphorous, soil depth, slope, direct solar radiation, area, isolation, and distance to the Gateway to the Narrows Trail. In general, the biotopes are within the habitat of the species, and a particular species composition is not maintained by the environment. The distribution of species among the hanging gardens in the Narrows is not strongly affected by their tolerances and requirements. High values of solar radiation seem to mete against the mosses and ferns, but these values occur in only 13 percent of the gardens sampled. The great dissimilarity between hanging gardens cannot be attributed to dissimilar habitats, although they are insular communities.

In this regard, the hanging gardens of the Narrows may be very different from those of the Arches and Canyonlands area. There the habitat differences found over a wide geographic area are more likely to be significant in affecting species presence and garden similarity. In the Narrows, the proximity of many gardens and their probable susceptibility to flash floods prevents a strict comparison with the research in eastern Utah. The Narrows presents a case in which we must look beyond the structure of the habitat to find an explanation of plant distributions. Malanson and Kay (in preparation) consider disturbance frequencies a likely alternative.

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Table 3. Class of environmental variable in which a species was most significantly limited (classes from Table 1).

Species	Distance	Isolation	Slope	Soil Depth	Soil Salinity	Solar Radiation	Water Salinity
Adiantum capillus-veneris					4		
Adiantum pedatum						3–5	
Aster eatonii			4–5				
Calamagrostis scopulorum					1–2		
Cystopteris fragilis	1					5	
Dodecatheon pulchellum	4–5					4–5	
Mimulus cardinalis						5	
Smilacina stellata		3–5		1			
Sphagnum sp.						3	3–4
Sphagnaceae sp.						1&5	1–2